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MANUAL CONTROL FOR THE MORL

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SUMMARY

Mission objectives and control system functions for the Manned Orbital Research Laboratory are outlined and a manual control concept for these functions is discussed. Laboratory operations console layouts and experimental program requirements are used to develop procedures for the manual control tasks. Evaluation of man's capability in controlling the laboratory motions under typical mission and emergency conditions has been made using the flight control simulator, and these data are compared with automatic system performance. The simulator results are then used to optimize the control system characteristics for the manual control mode.

INTRODUCTION

Experience in the Mercury program has shown that man is highly effective and reliable in performing the stabilization and attitude control tasks for space missions. As the duration of manned space missions is extended, manual control becomes increasingly valuable in enhancing the probability of mission success. One concept for long-term manned space missions, shown in figure 1, is the Manned Orbital Research Laboratory which has a lifetime of from 1 to 5 years. The complex experimental program currently being proposed for this laboratory also emphasizes the need for a manual control mode to perform normal mission maneuvers and for assuming command in emergency situations.

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MANNED ORBITAL RESEARCH LABORATORY

The MORL is basically a zero-gravity laboratory which will be utilized to conduct extensive experiments to study the environmental phenomena affecting manned space missions. The overall mission and control system configuration for this laboratory have been discussed in a previous talk by Mr. Kurzhals.

The scientific and engineering experiments to be performed by the laboratory directly affect the operation of the stability and control system. A preliminary evaluation of the proposed experimental MORL program indicates that approximately 30 percent of the time in orbit must be spent in special orientations in support of the experimental program. During the time spent in these experimental orientations, the control system monitoring and navigational tasks require particular attention. Also, the maneuvering of the laboratory to the various experimental orientations requires many specialized input commands to the control actuators.

To carry out the scientific and engineering experimental program assigned to the MORL, crew participation is employed to a large extent. Figure 2 shows the crew operations and experimental area of the laboratory. This portion of the laboratory contains both the experimental test apparatus and the displays and controls for the vehicle subsystems. The area is divided by four consoles into four approximately equal segments. A work station extends along one side of each console. One of these is the operations control and subsystem display station which handles the operational control of the vehicle and its critical subsystems. This console is operated by one or two men.

In addition to monitoring system operation and performing maintenance and calibration checks, the crew will also evaluate system performance information and issue commands to the vehicle by means of electrical and mechanical controls.

The displays and controls for the primary laboratory subsystems are located on the laboratory operations control and subsystem display console, which is illustrated in figure 3. Critical operational data are presented here in both visual and audible form. Two duty stations are represented. On the right side of the panel is the subsystems display station which presents graphically the status of all major systems aboard the vehicle, repeats critical warning and caution indications, and provides facilities for test and repair of onboard equipment. Equipment for engineering and scientific tests is primarily located at this station, as well as the checkout and calibration equipment for the laboratory subsystems.

The left-hand side of the operations console constitutes the operations control station, which provides the display control functions required for primary vehicle control. These include warning and caution panels for all critical system components, status displays for the laboratory secondary power system and reaction control system, guidance, navigation, and orbit keeping equipment, as well as sensor and actuator controls.

The operator will assess the status and condition of the systems and effect mode switching, sequencing, and dynamic control of the spacecraft. The television monitor, located centrally on this console, is used by the operator to monitor portions of the rendezvous and docking operation. Of particular interest on the operations console is that portion which displays dynamic functions to a crew member participating in the control loop and contains the manual actuators for controlling the laboratory attitude. The manual control philosophy is somewhat complicated by the cross-coupling torques inherent in the operation of the control moment gyros which comprise the MORL fine attitude control system. To compensate for these effects, optimum dynamic data display and optimum manual control procedures must be determined.

FLIGHT CONTROL SIMULATOR

The need for an optimum manual control philosophy has led to the development of a flight control simulator, which reproduces the MORL control console and manual actuators, as shown in figure 4. The console is linked to an analog computer which solves the laboratory and control system equations of motion with the manual inputs from the actuators. Three-axis attitude information is displayed by a three-axis ball indicator as well as by meters for fine attitude control. The angular rate information is also presented by meters. Required torque displays present command torque inputs to the operator. Torque inputs to the system are applied with the three-axis controller handle and are displayed adjacent to the required torque displays. The control system status is displayed and actuators are provided which allow the operator to unload the control moment gyros in the event that the system becomes saturated. Switches are also included to operate the laboratory attitude jets.

LABORATORY MISSIONS

The various missions proposed for the laboratory necessitate several attenuation settings which permit the displays and actuators to be operated at different levels, depending upon the mission. Characteristic laboratory missions which may be accomplished manually are shown in figure 5. This figure lists typical laboratory missions as well as the control tasks and accuracy requirements associated with each. Holding of the laboratory in its long-term orientation has been found in reference 4 to be relatively simple, although tedious.

Solar acquisition after occult involves maneuvering the laboratory through large angles to realine the solar panels with the sun. Rendezvous with either manned or unmanned vehicles may require maneuvering of the laboratory to the proper orientation and holding this orientation during the rendezvous and docking operation. Control missions during scientific and engineering experiments may vary widely and are not fully defined, but will probably involve attitude maneuvers and holds as well as specialized tasks such as target tracking.

Emergency conditions will require damping of laboratory angular rates and stabilization of the vehicle in the event of a system malfunction such as a reaction jet misfire or accidental collision during rendezvous and docking. Manual control may also be needed in the event of a primary sensor failure.

To evaluate man's ability to control the MORL, these missions have been flown on the flight control simulator. Let us look at some typical results of these manual flights. Performance data are shown in figure 6 for a maneuver of 10° in pitch and yaw. The entire operation is accomplished through the use of the control moment gyro system only. The time history shows the laboratory attitude errors in degrees plotted versus time in minutes. The manual performance compares very favorably with an automatic, closed-loop system using the same command torque inputs. Also note that the desired attitude is acquired and held to within 0.25°, which is within the mission requirements. Although this is a relatively small maneuver, the simulation has shown that attitude maneuvers of any magnitude are equally simple to accomplish provided sufficient time is allowed to complete the operation.

These results are typical of the data obtained from the flight control simulator. Several significant points have become apparent from the simulation concerning this concept of manual control philosophy. First, in figure 6, note that the effects of cross coupling on the third vehicle axis are very slight and compare well with the automatic system. This is significant for the precise performance of some experimental missions. Secondly, it has been found that the successful performance of the laboratory missions requires no training or experience. This fact may appreciably reduce the complex training which will be required for the crew of the MORL.

OPTIMIZATION PROCEDURE

The results of this study also indicate that the dynamic laboratory control tasks tend to become tedious and require the complete attention of the operator. This indicates the need for the development of an optimum manual control philosophy and operation procedures. The flight control simulator is being used in this optimization study.

Figure 7 outlines the method which is used to evaluate the relative effectiveness of operator and system performance. First, a standard of comparison or performance index must be selected. This must be a parameter which is indicative of overall system and operator effectiveness. As an example, let us consider the performance index α to be represented by the integral of the absolute value of attitude error e_0. The operator will be given an arbitrary period of time to perform a given mission. His resulting attitude error e_0 during the mission will then be integrated over the given time to determine the performance index α for the mission. Numerous runs of the same mission will yield a distribution of performance index which is determined from this plot of the frequency of achieving a particular value of performance index versus the performance index. From this plot a mean value of performance index may be determined as well as a standard deviation or the probability of achieving the mean value.

Mean values of performance index are then plotted versus significant control system characteristics such as the control system time constant. The minimum point of this curve will determine the optimum control system characteristics for a given performance index.

In actual practice, however, the problem of optimizing the manual control characteristics is more complex. As shown in figure 8, the selection of a single performance index for a complete evaluation is impossible and a more realistic index of performance will most likely consist of the weighted sum of a number of performance parameters. Typical examples of performance indices, represented by α, β, and γ, might be the integral of absolute attitude error, power consumption, and fuel expenditure, respectively. The constants C_1, C_2, and C_3 are weighting factors which will be arbitrarily chosen or determined by the mission requirements. The optimization procedure will also be based on several control system characteristics. Examples of these are control system time constant, torque level, and reaction jet size. Particular emphasis must be placed upon optimization with respect to those system characteristics which produce the greatest sensitivity in performance index.

This manual control optimization is presently being conducted with the flight control simulator. Several performance parameters have been selected as bases for the optimization of the manual control mode for the MORL. These include the integral of the absolute error, the total power consumed by the operation, and the total fuel expenditure. Let us now look at some representative results of the simulator study. Figure 9 shows the distributions of absolute error integral for several laboratory missions. Mission I is a 10° attitude maneuver command about the pitch and yaw axes.

Mission II involves the damping of 0.35° per second initial body rates about the pitch and roll axes. The control system time constant is 500 seconds. Mission III is identical to mission II except that the control system time constant here is 250 seconds. The figure shows the frequency, or percent probability of obtaining ±1 percent of a particular value of performance index, versus the performance index α in radian-seconds. It can be seen in each case that a mean value of performance index is clearly defined. Note also that the probability of achieving the mean value $\bar{\alpha}$ is almost 50 percent, indicating that the standard deviation is small and that operational consistency is very high.

In figure 10, the mean values of the performance index $\bar{\alpha}$, are shown versus control system time constant in seconds for missions I and II. The results here show the performance index α to be a rather strong function of control system time constant. They also indicate that additional flights are required to define the optimum system time constant but are illustrative of results of this optimization analysis.

The results that have been presented here are characteristic of the general trend of the simulator data. Additional mission profiles are currently being flown and several other performance indices are being considered. Relative weightings for the performance indices will be determined by the particular mission objective and by better definition of the MORL experimental program.

ADDITIONAL STUDIES

In addition to providing optimization of the control system characteristics, the flight control simulator is also being expanded to include more specialized missions and control concepts, thus defining the limits of manual capability and providing maximum flexibility in the manual control mode. These specialized missions will primarily consist of particular laboratory experimental missions and more specific emergency conditions resulting from various system failure modes. Other control system characteristics, such as on-off actuation of the control moment gyros, are being considered, as well as the integration of gyro and reaction jet control into the manual mode. In addition, the artificial gravity MORL configuration will be added to the simulation and operational techniques will be developed for manual control of this concept.

CONCLUSIONS

The flight control simulator discussed here will be used in an extensive investigation of the MORL manual control philosophy. Results from these experiments will be used to define an optimum and reliable manual control concept for the MORL. Present information indicates that manual control is feasible for this laboratory, and that optimization of this concept will allow man to precisely and reliably perform all the control mission objectives.

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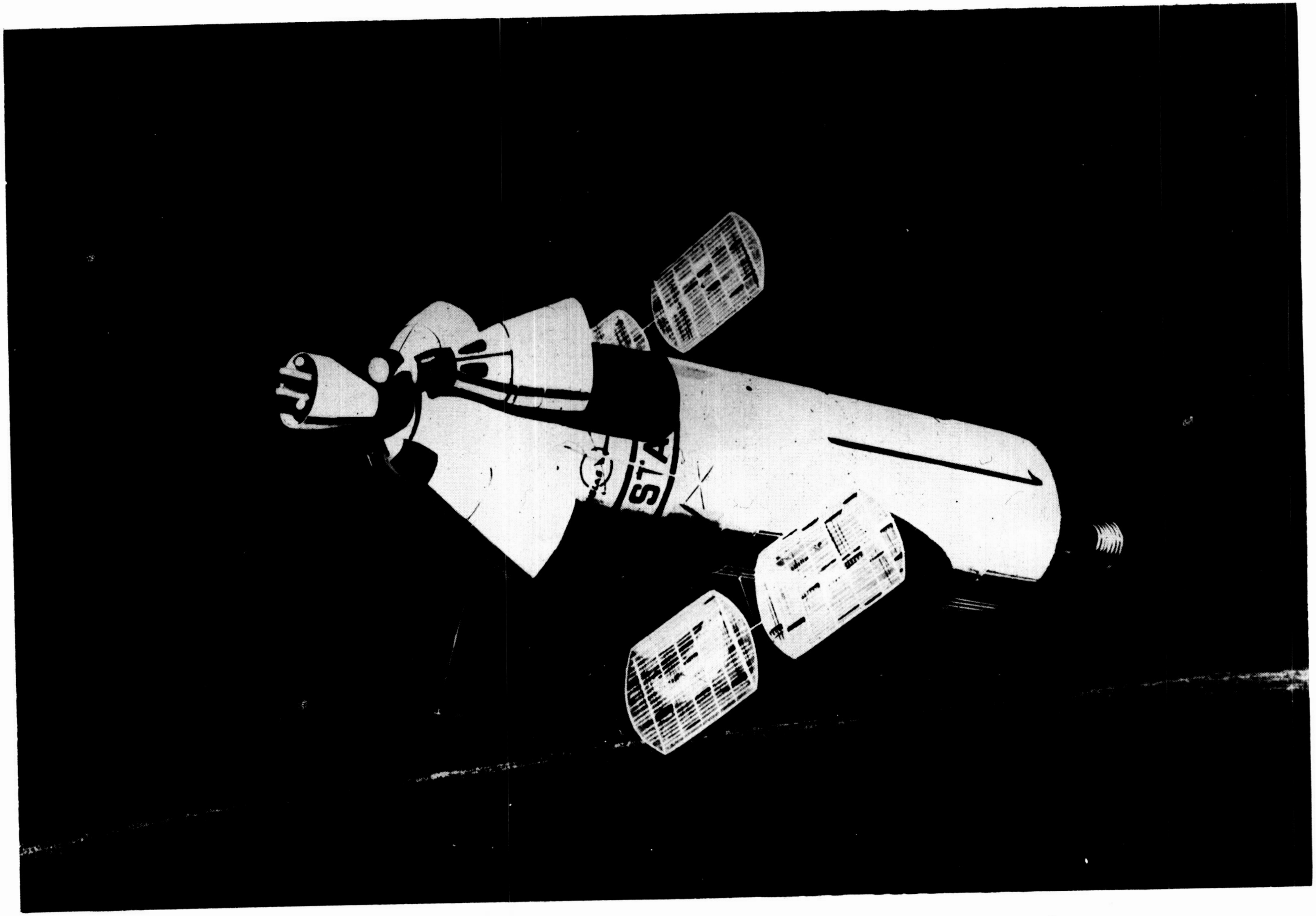

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Figure 1.- Artist's concept of nonspinning MORL.

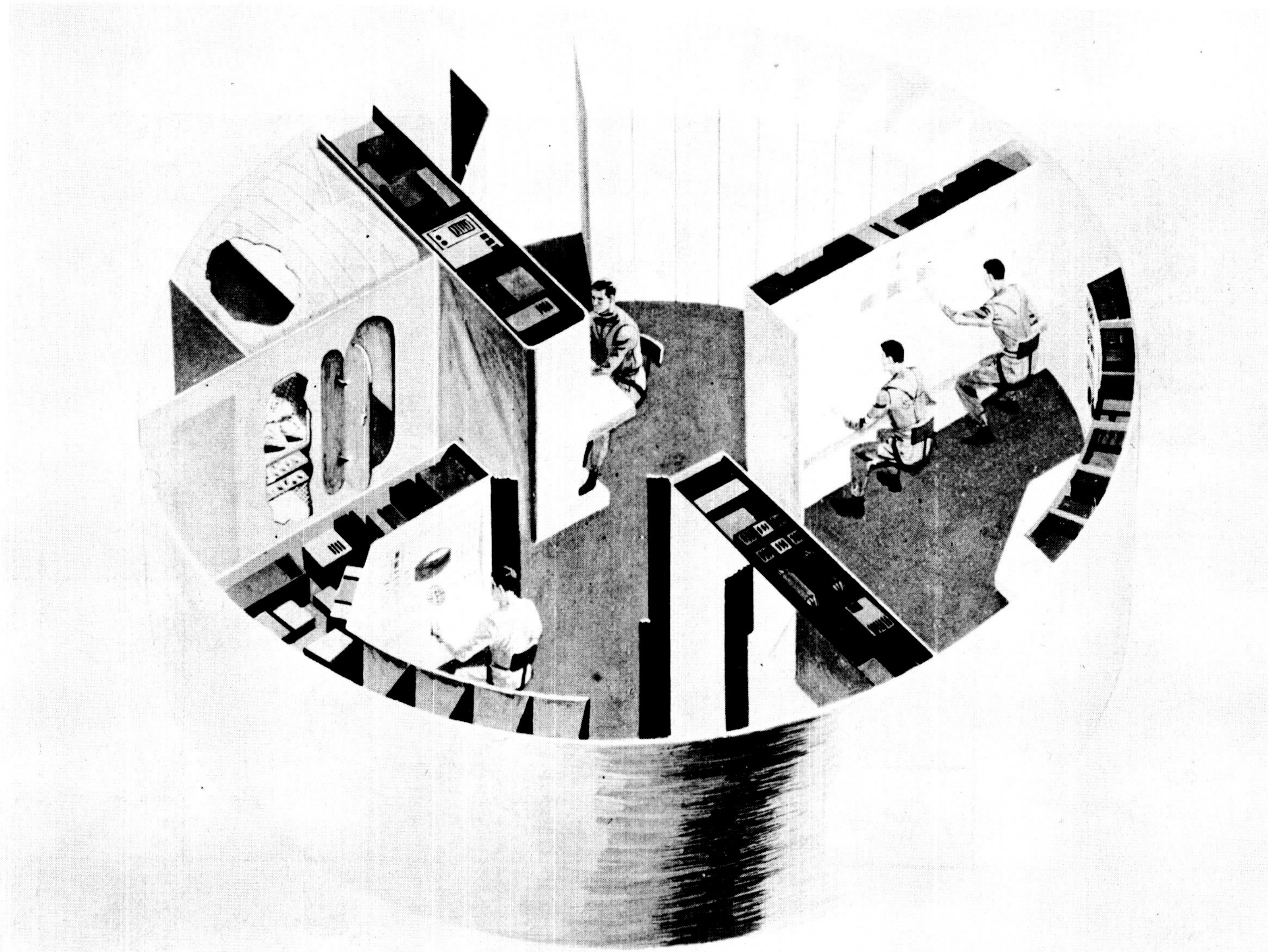

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Figure 2.- Crew operations and experimental area.

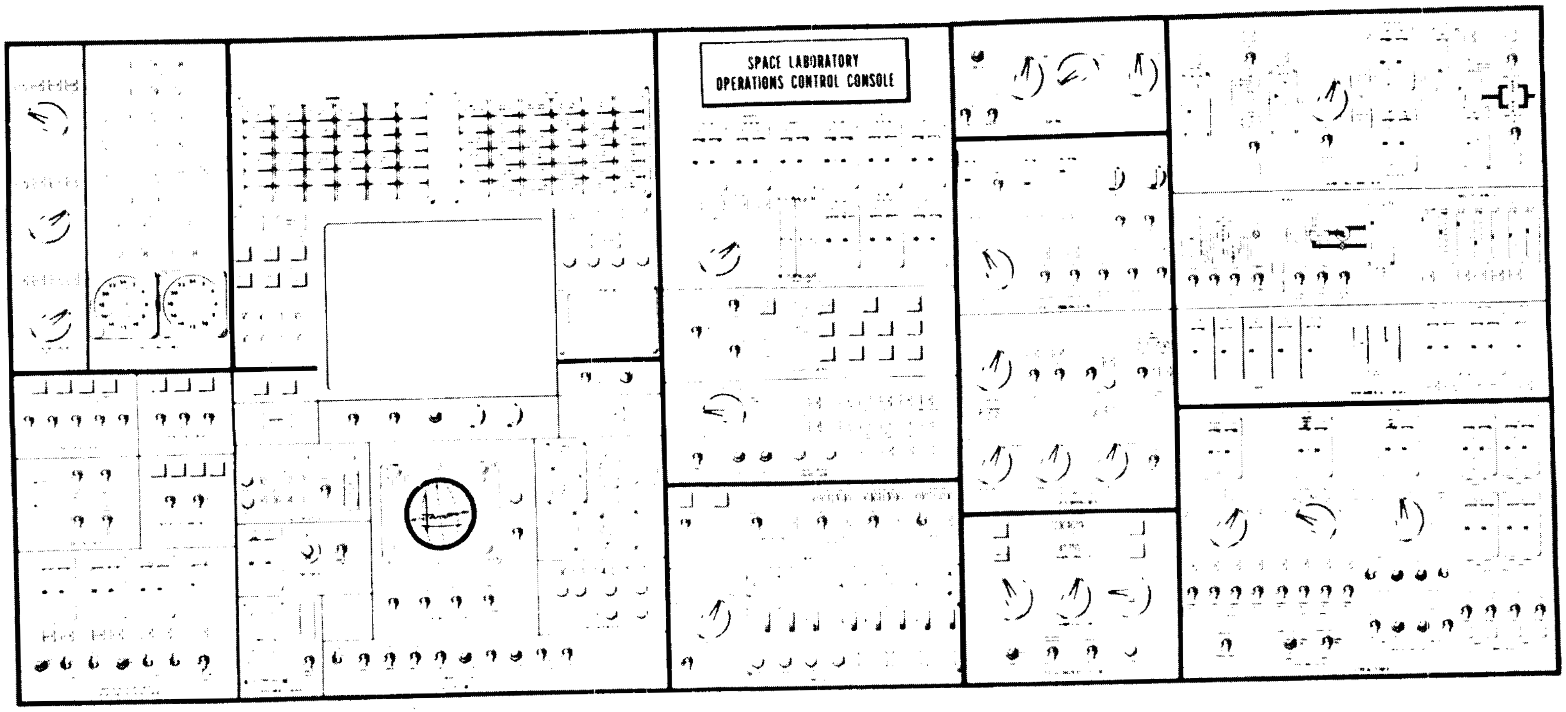

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Figure 3.- MORL operations and experimental console.

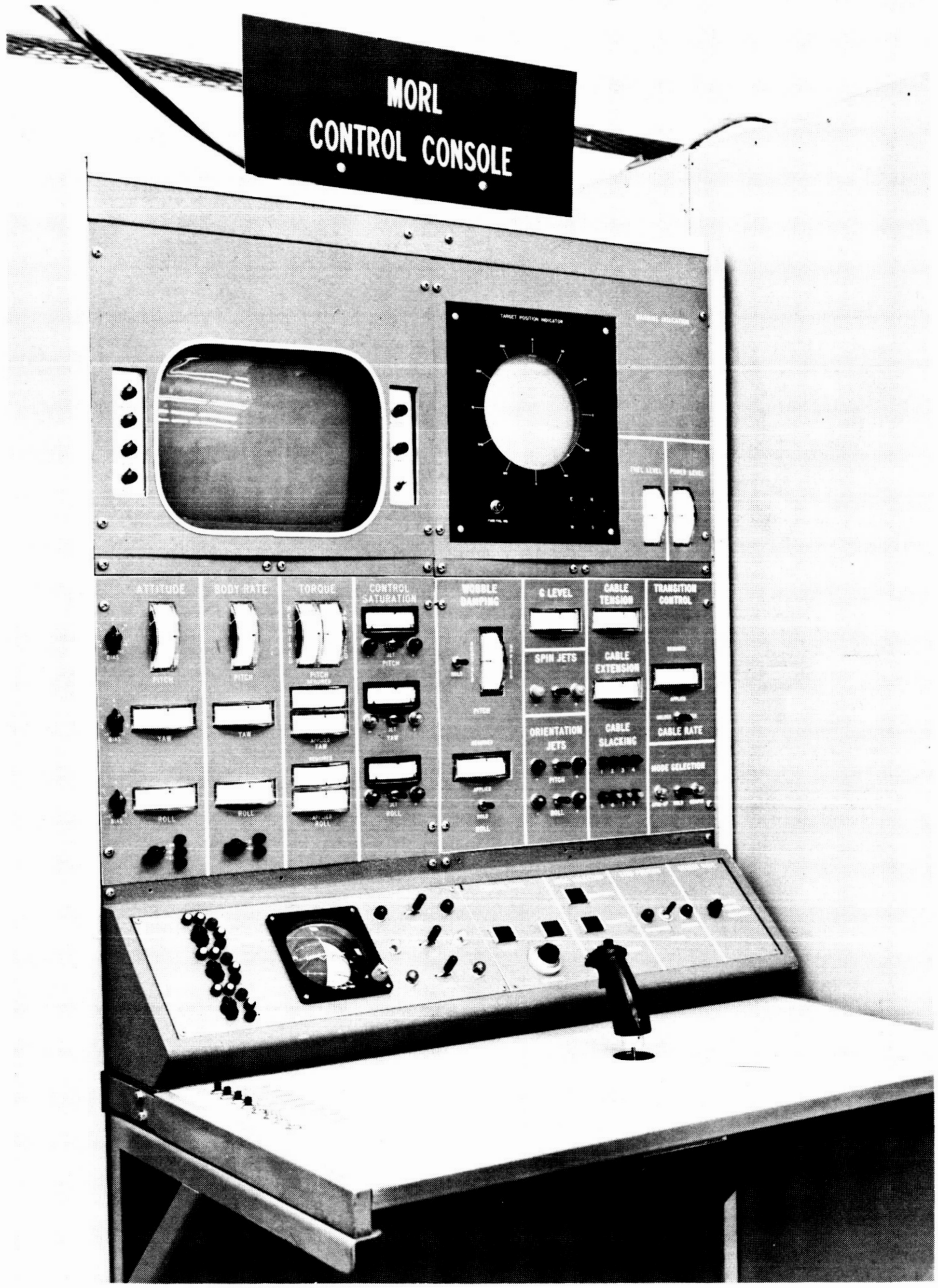

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Figure 4.- Flight control simulator.

MISSION	CONTROL TASK	REQUIRED ACCURACY
LONG-TERM ORIENTATION	ATITUDE HOLD	± .1°
SOLAR AQUISITION	ATTITUDE MANEUVER	± 10°
RENDEZVOUS	ATTITUDE MANEUVER ATTITUDE HOLD	± .5°
EXPERIMENT	ATTITUDE MANEUVER ATTITUDE HOLD TARGET TRACKING	± .15° - ± .5°
EMERGENCY	DAMP BODY RATES	NONE

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Figure 5.- Summary of MORL missions and control tasks.

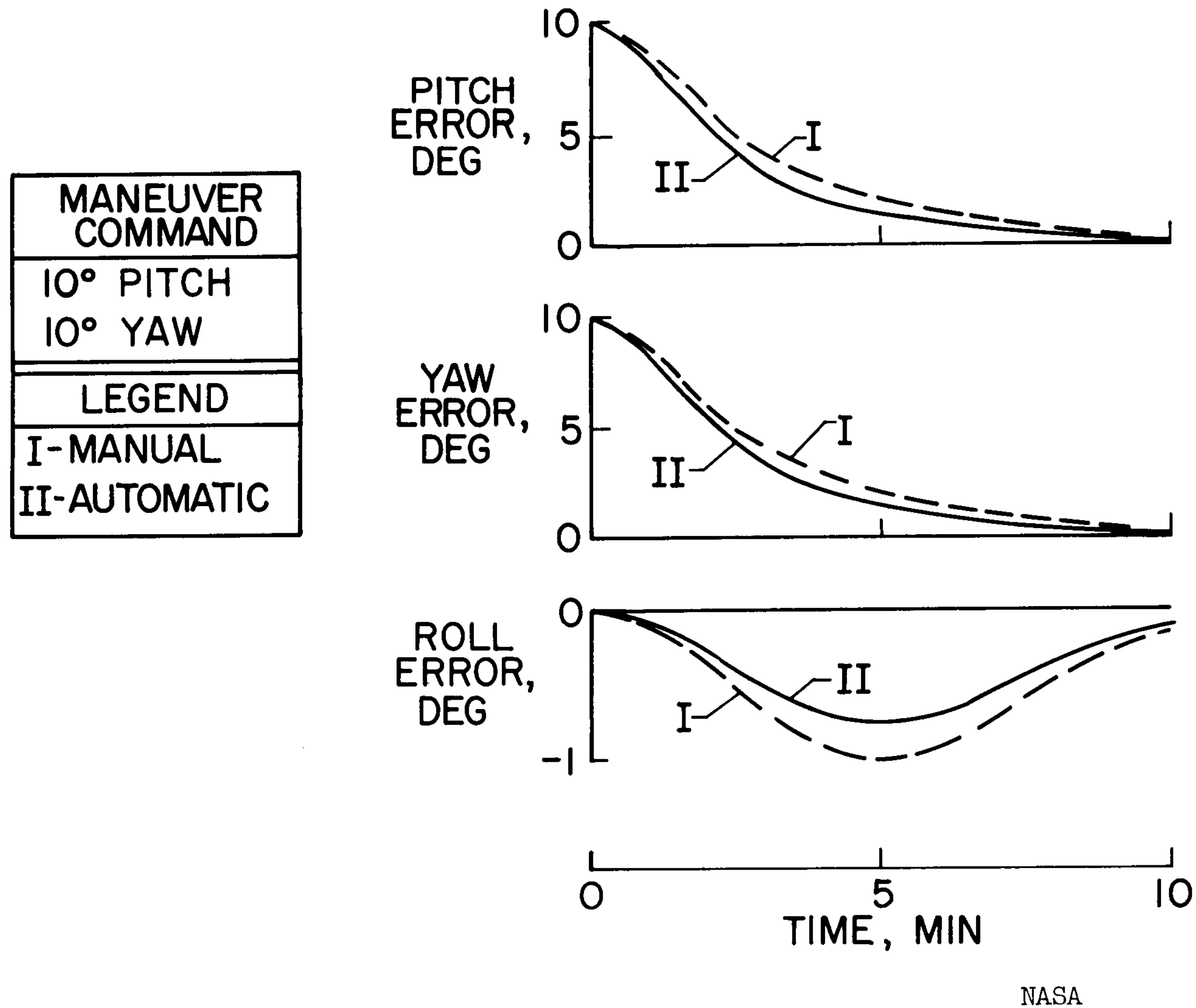

Figure 6.- Time history of typical laboratory maneuver.

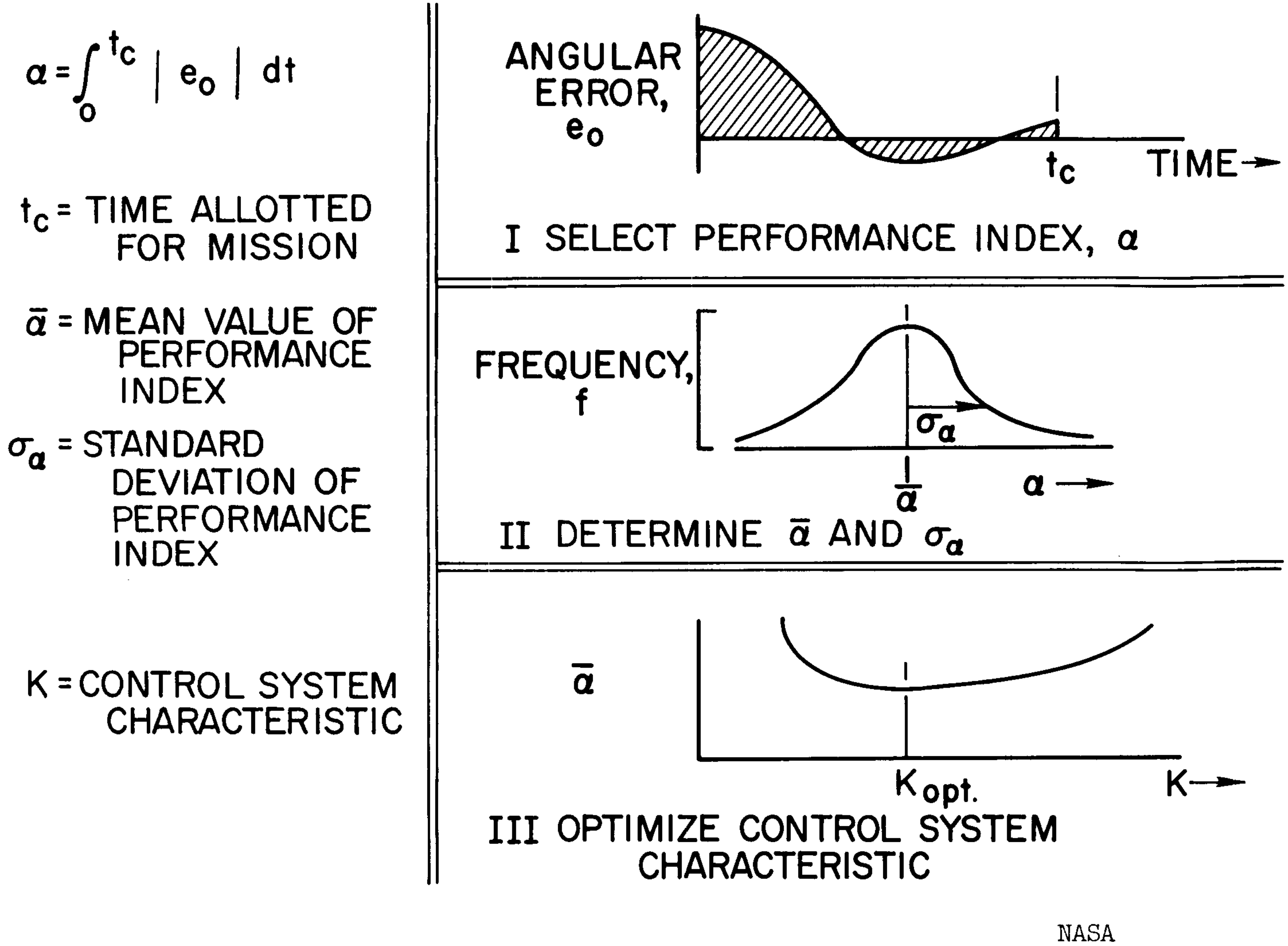

Figure 7.- Outline of manual control optimization method.

THE GENERAL OVERALL PERFORMANCE INDEX WILL BE EXPRESSED AS

$$\Phi = C_1 \alpha + C_2 \beta + C_3 \gamma + \bullet \bullet \bullet$$

WHERE

$$\alpha = \int_0^{t_c} |e_o| dt$$

$$\beta = \int_0^{t_c} (\text{FUEL})\, dt$$

$$\gamma = \int_0^{t_c} (\text{POWER})\, dt$$

ETC.

AND

C_1, C_2, C_3 = WEIGHTING FACTORS DETERMINED BY MISSION OBJECTIVE

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Figure 8.- Overall performance index.

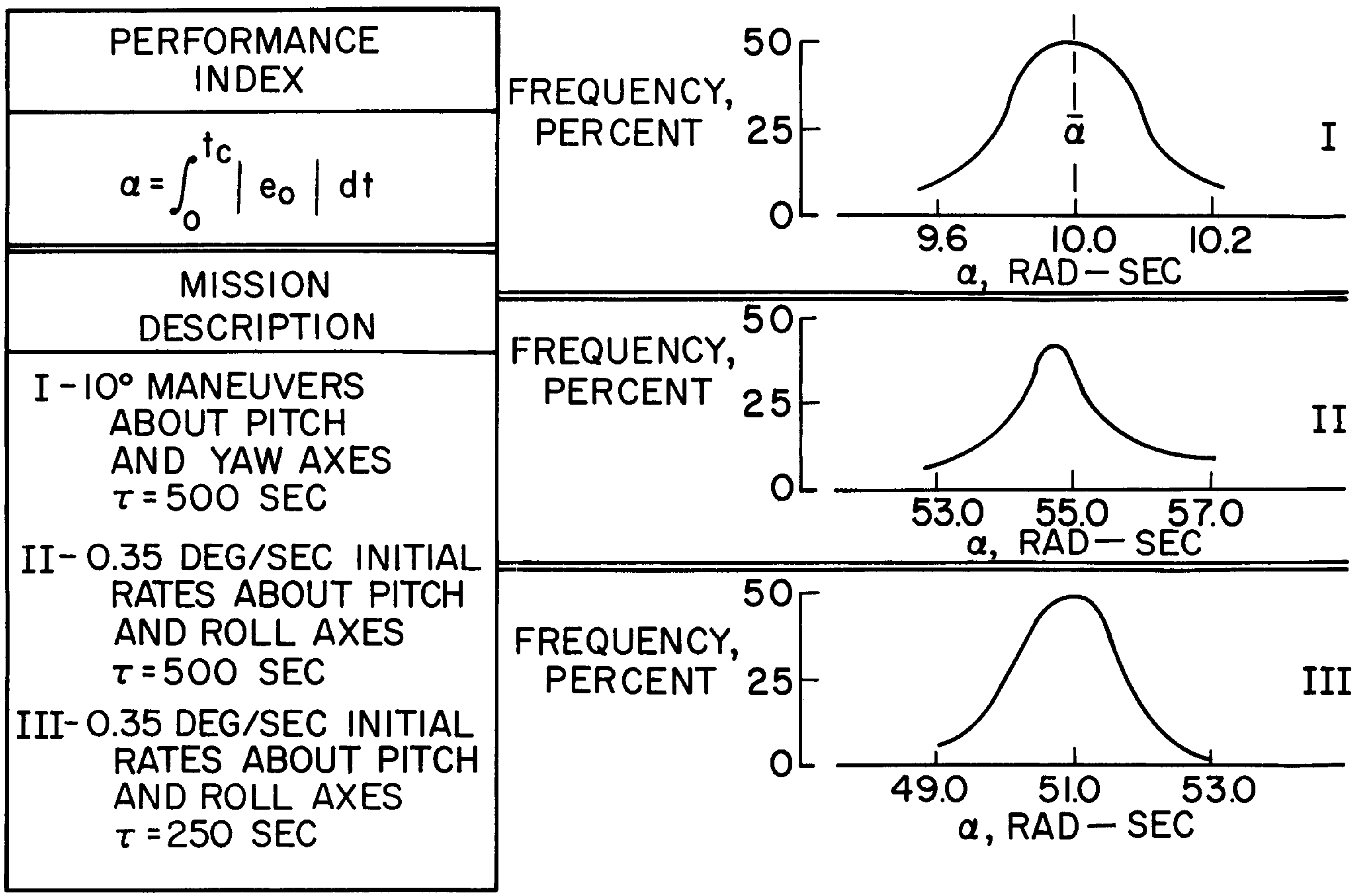

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Figure 9.- Distribution of performance index for typical missions.

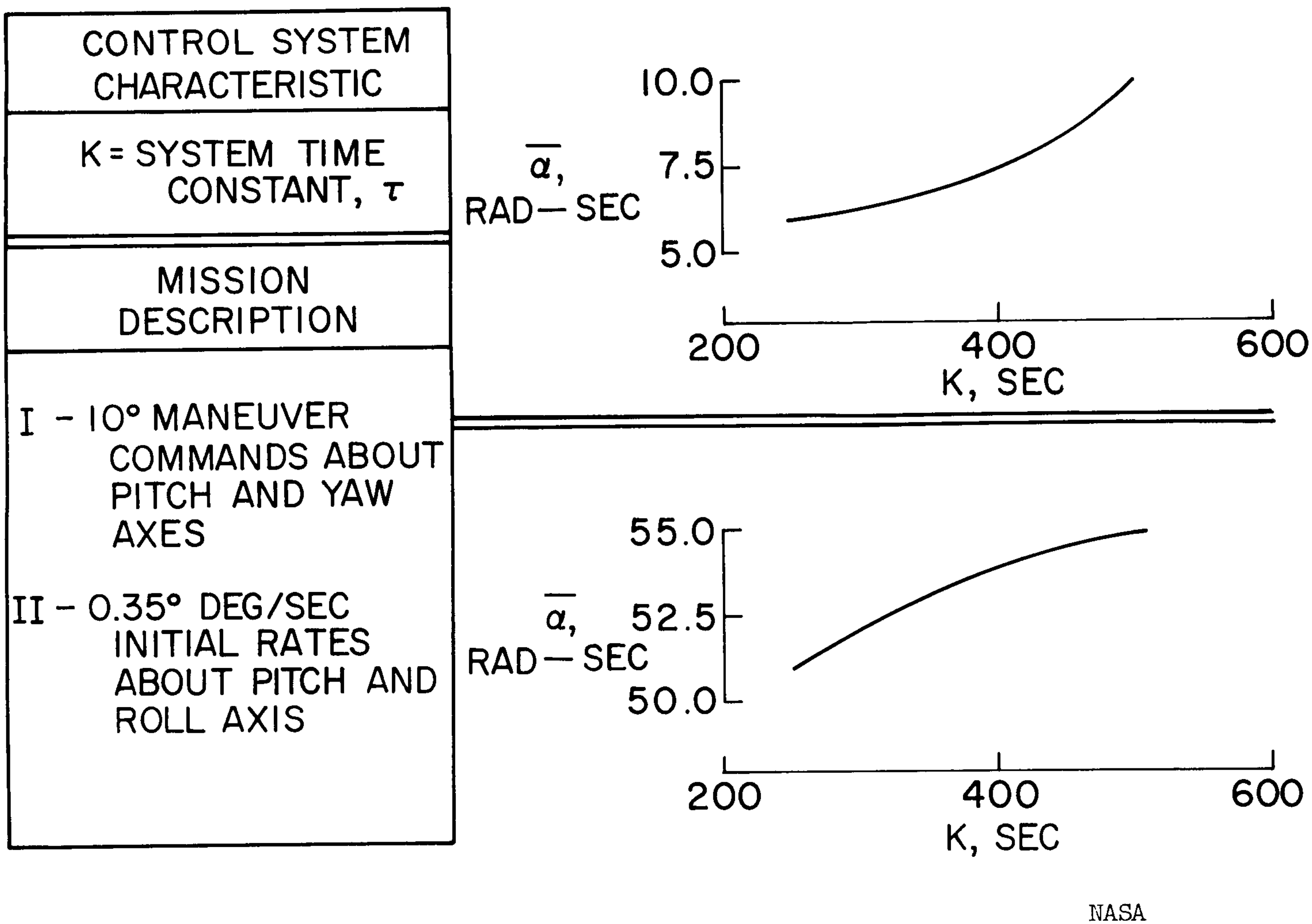

Figure 10.- Optimization of control system time constant.

NASA-Langley, 1964